# IEEE International Ultrasonics, Ferroelectrics, and Frequency Control 50th Anniversary Joint Conference

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**ABSTRACT REVIEW**

**Section Preference:** Frequency Control Group 2 - Oscillators Synthesizers & Noise
**Presentation Preference:** oral
**Is there a table included with your abstract?:** no

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**ABSTRACT TITLE**
The Photonic Delay Technique for Phase Noise Measurement of Microwave Oscillators

**ABSTRACT TEXT**
In this scheme the phase of the oscillator signal is compared to a delayed copy for decorrelation, and converted into a voltage for further analysis. The technique is based on the use of an optical fiber to provide the delay. This homodyne method is appealing because i) it is simple, ii) it does not require a reference oscillator, and iii) it is suitable to any frequency in a wide range, provided the delay be a non-resonant phenomenon. This feature is relevant to the measurement of certain low-noise oscillators that end up with odd frequency values.

At the state of the art, the optical fiber is the ideal delay element for a number of reasons. First and foremost it exhibits low attenuation (0.2 dB/km at $\lambda$=1.55$\mu$), which permits the implementation of a long delay, in excess of 100 $\mu$s (20km) in a single step, without amplification. By contrast, coaxial cables could never have been used effectively because of the large attenuation. For reference, the attenuation of a UT-141 semirigid cable (3.5 mm diameter) is 0.8 dB/m at 10 GHz. This limits the maximum length to some 50 m, thus the delay to 200 ns. Secondly, the fiber shows wide bandwidth, low thermal coefficient (dn/dT=$6.85\times10^{-6}$/K), and reasonable mass and size; for reference, a 10 km winding (50 $\mu$s delay) takes 1 kg and $1\times10^{-3}$ $m^3$. Finally, energy is perfectly confined inside the fiber, for EMC, grounding and shielding are no longer a problem.

Theoretical analysis and experiments shows that a fiber-based instrument features excellent sensitivity in the $10^2$ to $10^6$ Hz region of Fourier frequency f. At 10 GHz of carrier frequency, the sensitivity is of -120 to -80 dBrad$^2$/Hz at f=1 kHz, depending on the delay $\tau$. Presently, the sensitivity is limited by the 1/f$^3$ coefficient that results from the 1/f noise of microwave amplifiers and from the frequency-to-phase conversion inherent in the delay. A sensitivity of -100 dBrad$^2$/Hz is obtained with $\tau$=10 $\mu$s (2 km fiber). On the other hand, our method is not suitable to long-term measurement.

As an example of application, we measured the phase noise of a 100 MHz quartz oscillator multiplied to 9.9 GHz, and of

a 10.05 GHz photonic oscillator. The latter turned out to be simpler because the it has a $\lambda$=1.55 $\mu$m modulated output.

Most of our effort is spent in understanding the noise in the optical system, and the interaction between microwaves and optics.

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**KEYWORDS**
Phase noise
Optoelectronic oscillator
Microwave oscillator